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Bee and butterfly pollination in *Abutilon crispum, Malvastrum coromandelianum* and *Melochia corchorifolia*, and thrips and sunbird pollination in *Grewia orbiculata* (Malvaceae)

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ABSTRACT

Abutilon crispum is a shrub and *M. coromandelianum* and *M. corchorifolia* are herbs. Their growth and reproduction throughout the year depends on habitat conditions but they show prolific growth, flowering and fruiting in wet season. *G. orbiculata* is a deciduous tree species which displays leaf shedding, flowering, fruiting and leaf flushing events sequentially. Flowering occurs during dry season and the fruits mature in wet season. All four plant species are hermaphroditic, weakly protandrous, self-compatible, monomorphic and homostylous. Autonomous autogamy is functional in *A. crispum, M. coromandelianum* and *M. corchorifolia* exhibit autonomous autogamy. All plant species are facultative autogamous but this mating system is obligately vector-dependent in *G. orbiculata. A. crispum, M. coromandelianum* and *M. corchorifolia* are pollinated by bees and butterflies while *G. orbiculata* is pollinated by thrips and sunbirds. Therefore, facultative autogamy and entomophily ensure these plant species to invade and produce their populations in different ecological niches and flourish as invasive weeds.

Keywords: *Abutilon crispum, Malvastrum coromandelianum, Grewia orbiculata, Melochia corchorifolia*, autogamy, entomophily

1. INTRODUCTION

Malvaceae family is distributed worldwide in tropical regions (La Duke and Dobley 1995). The species in this family are mostly hermaphroditic and rarely dioecious or polygamo-monoecious which are adapted for entomophily (Taia 2009). In this family, the life forms have strong tendency towards herbaceous

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habit and the primitive species with tree or shrub habit displaying allogamous reproductive system are associated with bird-pollination (Gottsberger (1967, 1972; Sazima 1981). The humminbirds may have influenced the origin of bird flowers in this family in neotropics; the formation of staminal column by the union of the filaments is one evolved trait in the flowers to protect the ovary from the beak of probing birds (Grant 1950; Gottsberger 1986). The development of bat-pollination syndrome in this family is more recent and it has developed from the ancestors of bird-pollinated species in the neotropical regions. The plant traits such as forest habitation, woody habit and allogamy are considered to be chiropterophilous (Vogel 1969). In this family, the diversification of species and their migration into open areas or habitats has gradually contributed to the evolution of floral traits for bee-pollination. The bee-pollinated species often display lower woody or shrubby habit with annual or perennial depending on the habitat conditions towards the herbaceous habit. Autogamy is a derived character which is highly prevalent in plant species with herbaceous habit and this pollination led to their reproductive and evolutionary success as pantropical weeds. In bee-pollinated species, the flowers are non-tubular and more of open type. The staminal filaments bend along the whole length of staminal column facilitate free entrance to bees which while contacting the staminal column and the stigma pollinate and receive pollen for subsequent transfer to other flowers (Gottsberger 1986; Solomon Raju et al., 2021; Latha & Rao, 2021).

The genus *Abutilon* comprises of about 200 species of annual or perennial herbs, shrubs and small trees, distributed in the tropical and subtropical belts of the Americas, Africa, Asia, and Australia. Its species economically valuable due to fiber content and production of flavonoids, sterols, triterpenes, anthocyanins and fatty acids (Taia 2009; Gomaa et al. 2016). There is little information available on the pollination ecology of the species of this genus. Buzato et al. (1994) reported that *A. rufinerve, A. regnellii* and *A. aff. regnellii* display the floral features of both hummingbird and bat-pollination syndromes; they are pollinated by a bat species at night and by hummingbirds during daytime. But, the functionality of floral features point towards the bat-pollination syndrome. Abid (2006) reported that *A. fruticosum* is self-compatible and facultative autogamous which is functional through direct autogamy and insect-mediated pollination by bees and butterflies. Abid et al. (2010) reported that *A. indicum* is weakly protandrous, facultative autogamous, and its flower-opening and closing times are dependent on light and temperature. It is pollinated by bees of *Apis* and *Bembix* while butterflies use the flowers as nectar source without effecting pollination.

The genus *Malvastrum* is distributed primarily in tropical, subtropical and warm temperate parts of the New World. In this genus, the flowers are homogamous and adapted predominantly for autogamy but have the option for out-crossing. Three species, *M. americanum, M. corchorifolium* and *M. coromandelianum* have been introduced into tropical and subtropical regions of the Old World where they occur frequently in the coastal regions at low elevations. In India, these species have expanded their distribution with extensive animal and human disturbance. *M. americanum* is visited by a large variety of insects while *M. coromandelianum* is not visited by any insects (Hill 1982). Morato and Campos (2000) reported that *M. coromandelianum* is pollinated by bees, *Cephalurgus anomalus* and *Melissoptila cnecomala*. Mahale (2019) noted that *M. coromandelianum* is an important pollen and nectar source for honey bees. Shivanna (2014) reported that *M. coromandelianum* produces nectarless flowers which are open in the afternoon period and close back after 2 hours. It resorts to autogamous pollination, apparently during the process of petal closure. Keeping this in view, he stated that this species is evolving towards obligate autogamy by reducing the resource allocation for pollination services.

The genus *Grewia* comprises approximately 150 species of small trees or shrubs distributed in tropical and subtropical regions of the world (Sharma and Patni 2013). In India, 31 species of this genus have been recorded (Anonymous 2014). In this genus, several species are important in agro-forestry (Coleman 1982 Dev et al. 2017). Parmar (1976) reported that *G. asiatica* is a facultative autogamous and pollinated by pollen and nectar feeding honey bees. Sajjad et al. (2019) reported that *G. asiatica* is pollinated most efficiently by *Megachile cephalotes*. Zietsman (1991) reported that *G. occidentalis* shows three different timings of anthesis on the same individual tree; they are 0800-0900 h, 1200-1300 h and 1500-1600 h. It is protandrous (anther dehiscence in mature bud), self-incompatible, xenogamous and pollinated by *Apis mellifera* and *Xylocopa* spp. Veereshkumar et al. (2021) reported that *G. flavescens* is self-compatible but favors out-crossing by delayed self-pollination. It is pollinated mostly by *Megachile* bees followed by Apidae and Halictidae bees. Udikeri and Chandra (2019) reported that *G. subinaequalis* is pollinated by hymenopterans, dipterans and lepidopterans.

The genus *Melochia* has approximately 54 species which are distributed mainly in the neotropical parts from the United States to Uruguay with predominance in South America (Esteves 2012). The floral traits such as the presence of 5-carpelled ovary with 1 or 2 ovules in each carpel and 5 papillate styles in the apical portion characterize this genus (Goldberg 1967). A few species in this genus have been briefly investigated for sexual system and pollinators by different workers. Machado and Sazima (2008) reported that *M. tomentosa* flowers are homogamous, self-incompatible and pollinated by *A. mellifera, Centris* and *Xylocopa*. Ramirez and Navarro (2010) reported that *M. parviflora, M. tomentosa, M. villosa* var. *villosa* and *M. caracasana* are dimorphic and distylous while *M. crenata, M. nodiflora* and *M. pyramidata* var. *pyramidata* are monomorphic and homostylous. These authors also reported that *M. carcasana, M.*

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parviflora and *M. tomentosa* display generalist pollination system; the first is pollinated by flies, bees, wasps and butterflies, the second by bees, wasps and sphingids and the third by flies and bees. Shivanna (2014) reported that *M. corchorifolia* exhibits autogamous self-pollination and this pollination mode ensures its reproductive and evolutionary success.

With this backdrop, the aim of the study is to describe the floral biology and pollination aspects of four plant species of Malvaceae family, *Abutilon crispum, Malvastrum coromandelianum* (sub-family Malvoideae), *Grewia orbiculata* (sub-family Grewioideae) and *Melochia corchorifolia* (sub-family Byttnerioideae) which grow as weeds in tropical and subtropical regions of the world. The work reported in this paper is useful to understand the sexual reproduction and its association with insect pollinators and what makes them as successful weeds.

2. MATERIALS AND METHODS

Abutilon crispum growing wild on *Andhra University campus, Melochia corchorifolia* at *Kailasagiri* wild habitats in Visakhapatnam city, Visakhapatnam District, *Malvastrum coromandelianum* at the outskirts of Tirupati in Chittoor District and *Grewia orbiculata* near Sunnipenta, Srisailam in Kurnool District, Andhra Pradesh, India, were selected for the study during July-November 2021. The phenological events, vegetative growth/leaf fall/flushing, flowering and fruiting were carefully observed. Fifteen flowers from each plant species were used to note the floral morphological traits. The daily flower-opening schedules of each plant species were recorded; simultaneously anther dehiscence and stigma receptivity timings were noted. The flowers were carefully observed to know whether nectar is secreted or not, if so the quantity produced is noted. Observations on visitors to flowers were made during day to record their scientific names, the foraging behavior and forage collected. In case of birds, the observations were made whether they are probing the flowers legitimately or illegitimately and if visiting, the approach to nectar collection was recorded. All observations recorded were described systematically and discussed with the pertinent works.

3. OBSERVATIONS AND DISCUSSION

***Abutilon crispum* (L.) G. Don (Malvaceae: Malvoideae):** It is a perennial shrub which grows in degraded forests, wastelands, inland plains and rocky hill slopes throughout the country especially in warmer regions (Figure 1a). The stem is stout, branched and pubescent. The leaves are arranged alternately in two opposite vertical rows. The leaves are ovate, dentate and acuminate. The flowering occurs throughout the year in areas with enough soil moisture but profuse vegetative growth, flowering and fruiting occurs during wet season (Figure 1b). The flowers are borne solitary in axillary and terminal positions, pedicellate, light yellow, scentless and hermaphrodite (Figure 1c,d). The calyx is divided into 5 ovate green lobes with short sharply pointed tips. The corolla has 5 overlapping light yellow papery petals which are fused at the base and the petals open to different extents from trumpet shape to nearly flat state. The staminal column has multiple stamens fused into a column which is lined with anthers (Figure 1e). The ovary is multilocular with ovules on axile placentation (Figure 1g). The style is branched and tipped with head-like stigmas which are spatially separated from the stamens. The fruit is a globular stellate pubescent drooping schizocarp (Figure 1h) with 10 mericarps which are rounded at apex and base and each mericarp has a single reniform dark brown seed.

Mature buds are open gradually by the unfold of petals during 0700-0900 h. The unfolded petals expose the entire staminal column and branched style with stigmas. The anthers dehisce by longitudinal slits during mature bud stage; in the staminal column, the upper anthers dehisce early to the lower anthers. The pollen output per anther is 325 ± 21.23 (Figure 1f). The stigmas attain receptivity to pollen after the unfolding of petals. The nectar is secreted in minute quantity which is situated at the base of the staminal column around ovary. The petals close back by the evening and remain closed until flower drop which occurs after 3-4 days. Bees (*Apis cerana, A. florea, Trigona iridipennis* and *Ceratina* sp.) and lycaenid butterflies (*Freyeria trochylus, Chilades pandava, Zizeeria karsanda, Pseudozizeeria maha* and *Zizula hylax*) visited the flowers as soon as the petals unfolded and continued their foraging activity until 1600 h; the bees foraged for both pollen and nectar while the butterflies foraged for nectar only. The foraging activity of both bees and butterflies invariably led to contact between their body parts (forehead and ventral side of the bee body, and proboscis, wings and ventral side of the butterfly body) and the floral sex organs resulting in either self- or cross-pollination. Further, the bees never distinguished between the anthers and the stigmas and hence attempted to collect pollen also from stigmas; such a foraging behavior facilitated and promoted the occurrence of pollination.

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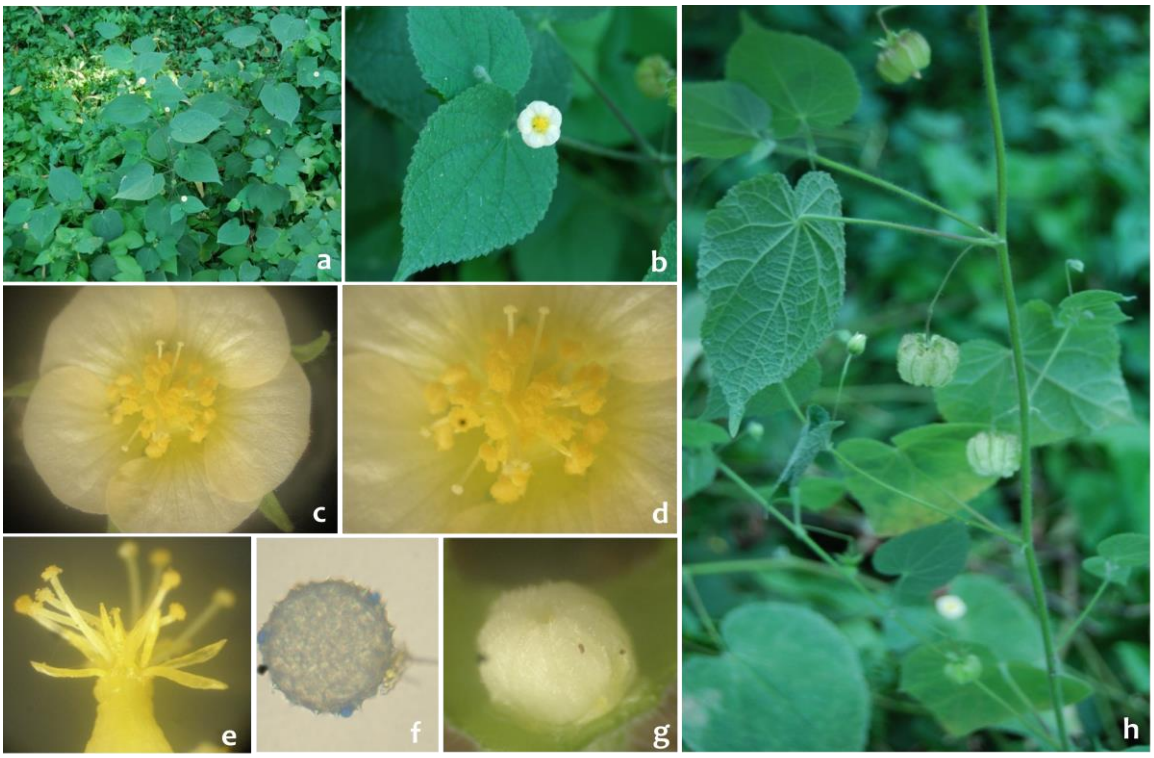

Figure 1. *Abutilon crispum*: a. Habit, b. Twig with flower, c. & d. Close-up view of flower, e. Position of stamens, f. Pollen grain, g. Ovary, h. Fruits.

Buzato et al. (1994) reported that *Abutilon rufinerve, A. regnellii* and *A. aff. regnellii* overlap their floral features between chiropterophilous and ornithophilous pollination syndromes. They are bell or bowl-shaped pinkish or purplish or yellowish corolla, dusk or dawn time anthesis and very faint cabbage odor. With these floral traits, these plant species are pollinated by a bat species at night and by hummingbirds during daytime. Abid (2006) reported that *A. fruticosum* is self-compatible, facultative autogamous which is functional through direct autogamy and insect-mediated pollination. Bees are the pollinators while butterflies are simply visitors to the flowers. Abid et al. (2010) reported that *A. indicum* is a protandrous and facultative autogamous species and visited by butterflies and bees for forage collection but only bees act as pollinators. In the present study, *A. crispum* with light yellow flowers provide free access to visiting insects to collect both pollen and nectar. The insects that visit the flowers are bees and lycaenid butterflies; the former collects both pollen and nectar while the latter collects only nectar. Both categories of insects are involved in pollination act while collecting the intended forage. Bees lack discriminatory behavior to distinguish between the anthers and the stigmas due to which they could promote pollination rate by transferring pollen more effectively to the stigmas. The pollen output per anther is very low but this is compensated by the production of many stamens per flower. Since pollen amount available in each anther is not much, the bees are compelled to visit as many anthers as possible within a flower during which they visit the anthers in a zig-zag fashion facilitating the transfer of more pollen to the stigmas. Further, the bees may not collect pollen from all the anthers of a flower in a single visit and hence there is a possibility for bees to make repeated visits to the same flowers in quest of more pollen and also nectar; such a possibility increases the chances of occurrence of pollination, especially out-crossing.

In *A. crispum*, the floral aspects such as morning anthesis, light yellow corolla, nectar production and copious levels of pollen production indicate that it is adapted for pollination by diurnal foragers. Accordingly, only diurnal insects, bees and butterflies utilize the flowers of *A. crispum* as forage source and hence it can be stated that this plant species is typically entomophilous. In this species, the short duration of open state of corolla and exposure of sex organs, and low pollen production per anther indicate that it is facultative autogamous facilitating autonomous self-pollination. Insect foragers mediate self- and cross-pollination while collecting the forage during the open state of the corolla. The closed flowers being in place could provide additional attraction to the foragers and also it is necessary for the species to retain the flowers for about 3-4 days because the flowers are borne solitary. Therefore, *A. crispum* is a facultative autogamous and entomophilous which ensures it to grow as a successful weed.

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***Malvastrum coromandelianum* (L.) Glarcke (Malvaceae: Malvoideae):** It is a woody-rooted perennial herb with several strong cylindric stems at base and spreading branches (Figure 2a). It grows in principle during rainy season but it continues its growth almost throughout the year in wet habitats. In such habitats, it produces several batches of new individuals due to seed germination within 3 weeks after being shed from the parental plants. The leaves are petiolate, simple, helically alternate and lanceolate-ovate. The vegetative growth, flowering and fruiting occur sequentially or sometimes partially overlapped during rainy season. The flowers are pedicellate, bisexual, and borne solitary in axillary and terminal positions. The calyx has 5 green campanulate valvate lobes with acuminate apex and armed with stellate hairs along inside and outside margins. The corolla has 5 fan-shaped overlapping petals which are united basally to the staminal column; the petal base has marooned colored marks overarched by golden yellow color and followed by white color. The staminal column has multiple monadelphous stamens bearing basifixed, monothecal anthers. The ovary is hidden beneath the staminal column; it consists of 10-14 carpels each with 1 ovule. The style is with 10-14 tentacle-like branches, each branch indicating a locule; the apical portion of each style branch is tipped with a capitate stigma. Nectar is secreted in minute quantity at the base of the flower. The fruit is an indehiscent schizocarp consisting of 10-14 dry 1-seeded reniform indehiscent mericarps partially crowned by an overarching, dry calyx. The seed is dark-brown, heart-shaped and tightly fit into the locule.

Figure 2. *Malvastrum coromandelianum:* a. Habit, b. *Apis cerana* collecting nectar, c. *Apis florea* collecting nectar, d. *Trigona iridipennis* approaching to collect nectar, e. Pierid butterfly, *Anaphaeis aurota* collecting nectar, f. Nymphalid butterfly, *Junonia lemonias* collecting nectar.

In *M. coromandelianum*, the mature buds are open during 0700-0900 h and the male and female sex organs mature nearly synchronously at anthesis. The flowers were visited only during daytime by bees and butterflies; the bees were *Apis cerana* (Figure 2b), *A. florea* (Figure 2c) and *Trigona iridipennis* (Figure 2d) while the butterflies were the pierid, *Anaphaeis aurota* (Figure 2e) and the nymphalid, *Junonia lemonias* (Figure 2f). The bees foraged for both pollen and nectar during 0700-1700 h with more activity during 0900-1200 h while butterflies foraged for nectar only during 0800-1600 h with almost uniform pattern of visitation rate. Both these insects while collecting the forage legitimately effected self- and/or cross-pollination depending on the source of pollen. Bees tended to spend more time for forage collection as they are involved in voracious pollen collection and additionally nectar collection while butterflies tended to move quickly from flower to flower in quest of more nectar collection as the flowers offer only minute nectar quantity.

In *M. coromandelianum*, the stigmas are erect at anthesis and stands below the height of anthers but they gradually bend down curling into dehisced anthers due to gradual closure of petals at the time of sunset. Such a movement of the stigmatic lobes and their consecutive contact with the dehisced anthers during petal closure time facilitate the occurrence of autogamy without fail since there is ample pollen is still available despite the collection of pollen by bees because the stamens are many and each stamen produces specific amount of pollen.

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Hill (1982) documented that in the genus *Malvastrum*, the flowers are homogamous with the maturation of stamens and stigmas at the same time. In this genus, autogamy is the predominant mode of pollination although out-crossing occurs with the involvement of insects. He also noted that in out-crossing species of this genus, the petals are conspicuous and nearly flat providing a landing platform for foraging insects. The flowers with multiple anthers with echinate pollen facilitate to secure some pollen grains by the foraging insects. Additionally, the papillose stigmas in these flowers facilitate efficient adherence of pollen when the pollen-laden forager comes in contact with them. Further, he also stated that the flowers offer only minute nectar as a reward and in view of this, the foragers are mainly attracted to the large amount of pollen produced collectively by all anthers of a flower put together. In *M. coromandelianum*, the flowers present the characteristics explained above to achieve autogamous pollination without the involvement of foragers by bending down and curling their stigmas amidst dehisced anthers, the process of which is facilitated by the gradual closing of the petals by the time of sunset and self- and cross-pollination by foraging insects. Shivanna (2014) reported that *M. coromandelianum* flowers are nectarless, open during afternoon hours and close back after 2 hours. In the present study, it is found that *M. coromandelianum* flowers are nectariferous but the nectar secreted is in minute quantity. The flowers are open during morning hours and close back by late evening.

Hill (1982) reported that *M. americanum* is visited by different species of insects while M. coromandelianum has never been visited by insect pollinators. Morato and Campos (2000) reported that M. coromandelianum is pollinated by two pollen and nectar collecting bee species, *Cephalurgus anomalus* and *Melissoptila cnecomala*. Mahale (2019) reported that *M. coromandelianum* is an important source of pollen and nectar for honey bees. Shivanna (2014) reported that *M. coromandelianum* appears to evolving towards obligate autogamy by reducing the resource allocation for pollination service. In the present study, it is found that *M. coromandelianum* flowers produce copious amount of pollen along with a minute quantity of nectar which indicates that the point of reducing resource allocation for pollination service does not arise. The flowers have been visited by pollen and nectar collecting bees and nectar-collecting butterflies, which while collecting the forage effect pollination. Further, this floral source serves as an important source of pollen and supplemented by little amount of nectar for honeybees. Therefore, *M. coromandelianum* with the function of autogamous pollination and vector-mediated pollination typifies the function of facultative autogamous mating system which ensures this plant to grow as a successful weed.

***Grewia orbiculata* Rottl. (Malvaceae: Grewioideae):** It is a deciduous tree species that grows in dry habitats. The leaves are petiolate and broadly obovate with dentate margins. Leaf shedding, flowering, fruiting and leaf flushing events occur sequentially. Flowering occurs during dry season (Figure 3a) and the pollinated flowers begin to produce fruit and seeds immediately but maturation of fruits occur only during wet season. The inflorescence is a pedunculate umbel-like cyme with 2-4 pedicellate yellow hermaphroditic flowers borne in axillary or terminal position of the branches (Figure 3b). The calyx consists of 5 linear-spathulate pubescent yellow sepals. The corolla consists of 5 yellow petals which are shorter than sepals and equipped with a nectariferous gland at the base. The stamens are many, free and borne on a short torus. The ovary is hirsute and 2-4 loculed with ovules inside with a long style extended beyond the level of anthers and tipped with a capitate or star-shaped 4-lobed stigma. Fruit is a globose indehiscent obscurely 2-lobed hairy drupe with 2-4 pyrenes.

In *G. orbiculata,* the mature buds are open during 0700-0900 h (Figue 3c-e) and anther dehiscence occurs shortly before anthesis. The nectar is secreted in traces and located behind the staminal torus around the ovary. The stigma attains receptivity shortly after anthesis and glistens against sunlight due to exudate that is out and placed on the stigma surface. The flowers are quite attractive due to bright yellow color of sepals and petals to the flower visitors but insect visitors were never seen seeking either pollen or nectar from the flowers during the observation period. The flower present thrips which act as resident foragers-cum-pollinators. The thrips use floral buds for their breeding and pollen and nectar as food after anthesis. The sunbirds, *Nectarinia asiatica* (Figure 3f) and *N. zeylonica* (Figure 3g) collect traces of nectar and at the same time also collect thrips that move within the flowers by legitimate probing. These birds act as pollinators due to establishment of contact between its beak and the upper portion of ventral abdomen and the floral sex organs. But, they are not appropriate foragers since the flowers are not important nectar source as it is produced in traces. Since the birds were unable to collect nectar from other floral sources in the habitats, they were found resorting to use *G. orbiculata* flowers as nectar source.

Parmar (1976) reported that *G. asiatica* is a facultative autogamous and pollinated by pollen and nectar feeding honeybees. Sajjad et al. (2019) reported that *G. asiatica* is pollinated most efficiently by *Megachile cephalotes*. Zietsman (1991) reported that *G. occidentalis* shows anthesis daily during 0800-0900 h, 1200-1300 h and 1500-1600 h on the same tree. It is protandrous, self-incompatible, xenogamous and pollinated by *Apis mellifera* and *Xylocopa* spp. Veereshkumar et al. (2021) reported that *G. flavescens* is self-compatible but favors out-crossing by delayed self-pollination. It is pollinated mostly by *Megachile* bees followed by Apidae and Halictidae bees. Udikeri and Chandra (2019) reported that *G. subinaequalis* is pollinated by hymenopterans, dipterans and

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lepidopterans. In the present study, *G. orbiculata* is weakly protandrous and pollinated by thrips and sunbirds, the thrips are important in self-pollination in the same flowers and in different flowers by geitonogamous pollen transfer while the sunbirds are important both self- and cross-pollination. The traces of nectar produced by individual flowers and small amount of nectar by all flowers open on a given day on the same tree compel the sunbirds to seek nectar from different conspecific individuals of this species in order to satiate their nectar requirement. Such inter-tree nectar foraging activity by sunbirds facilitate the promotion of the occurrence of cross-pollination benefiting the tree to produce genetically viable fruit/seed production. Nevertheless, *G. orbiculata* with its blooming season occurring in dry season is benefiting the sunbirds to obtain nectar when other floral resources are either unavailable or not suitable for their foraging. Therefore, *G. orbiculata* is able to achieve both self- and cross-pollination even when insect pollinators are not available in the habitat. The absence of insect pollinators during the blooming season of this tree species could be attributed to unfavorable ambient environmental conditions which prevent their flying and foraging activity.

Figure 3. *Grewia orbiculata:* a. Flowering tree, b. Flowering inflorescence, c. Mature bud, d. & e. Flowers, f. *Nectarinia asiatica* (male) feeding on thrips, d. *Nectarinia zeylonica* (female) collecting nectar.

***Melochia corchorifolia* L. (Malvaceae: Byttnerioideae):** It is an annual or perennial herb that grows in open areas and wastelands and even along highways (Figure 4a). The leaves are petiolate and ovate with intensely serrated margins. The plant begins to appear in July and display full vegetative growth by August. The floral buds begin to appear by early August and first flowers appear by the 3rd week of August; the flowering extends until November. Later, the plant disappears in dry habitats while it continues to flower and fruit in wet habitats. The inflorescence comprises of crowded cymes with linear bracts. The flowers are purple, bisexual, monomorphic and homostylous. The calyx is campanulate with 5 green lance-shaped sepals fringed with hairs. The corolla is purple with yellow throat, bell-shaped with 5 shortly clawed petals. The stamens are 5, free and the filaments are united into a tube almost to the top. The ovary is 5-celled with 2 ovule in each cell; the styles are 5 which are combined at the base. The fruit is a 5-valved capsule with 1 brown angular seed in each locule.

In *M. corchorifolia*, the mature buds are open during 0700-0900 h (Figure 4b) and anther dehiscence takes place just before anthesis. The stigma attains receptivity after anthesis and placed at or slightly above dehisced anthers which facilitates the occurrence of autogamy but it was not tested. The nectar secreted by the nectary lining the inner base of connate calyx is accumulated in the space between the corolla and calyx; it is secreted in traces only. The flowers remain fresh and attractive on the day of anthesis and they show signs of fading on the 2nd day and fall off later or remain in place in wilted form. The flowers were visited by honey bees, *Apis cerana* and *A. florea* (Figure 4c,d) and by lycaenid butterflies, *Castalius rosimon* (Figure 4e) and *Jamides bochus* (Figure 4f). But, other lycaenid butterflies may also visit the flowers if present in the habitat. The bees foraged for both pollen and nectar throughout the day from 0700 to 1700 h with more activity at 0900-1200 h while butterflies foraged for nectar from 0800

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to 0200 h only. The bees as well as butterflies had contact with both dehisced anthers and stigma while probing the flowers for forage and effected pollination. The bees spent more time to collect pollen and/or nectar in each visit when compared to the time spent at each flower by butterflies. Based on this, it is inferred that although the visits of both bees and butterflies result in pollination, butterflies promote cross-pollinate rate.

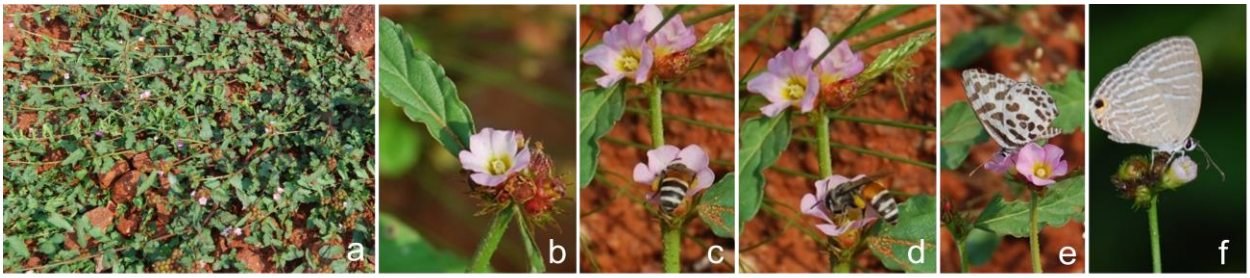

Figure 4. *Melochia corchorifolia:* a. Habit, b. Flower, c. *Apis florea* collecting nectar, d. *Apis florea* collecting pollen, e. & f. Lycaenid butterflies collecting nectar – e. *Castalius rosimon*, f. *Jamides bochus*.

In *Melochia* genus, distyly functional through pin and thrum morphs does not occur in all species (Ramirez and Brito 1990; Machado and Sazima 2008). Consolaro et al. (2005) reported that distylous self-compatible populations may shift into homostylous populations while Bawa and Beach (1981) noted that distylous populations may change into dioecious populations. Arroyo and Dafni (1995) documented that different selective pressures promote the instability of distylous condition and the origin of homostylous condition from a distylous ancestor. Charlesworth and Charlesworth (1979) reported that transitions to gender dimorphisms appear to be stimulated by changes in pollination service. Arroyo et al. (2002) stated that floral traits and pollinators have a role in the stability of distyly. The flowers of open type or with short corolla tube may facilitate pollination by generalist pollinators which have short mouth parts. Machado and Sazima (2008) reported that *M. tomentosa* is homogamous and self-incompatible. Ramirez and Navarro (2010) reported that *M. parviflora, M. tomentosa, M. villosa* var. *villosa* and *M. caracasana* are dimorphic and distylous while *M. crenata, M. nodiflora* and *M. pyramidata* var. *pyramidata* are monomorphic and homostylous. Shivanna (2014) reported that *M. corchorifolia* exhibits autogamous self-pollination. In the light of these generalizations and findings, the present study finds that *M. corchorifolia* flowers are of open type, short-tubed, monomorphic and homostylous providing easy access to nectar seeking insects and hence these floral traits characterize generalized pollination system because bees and butterflies visit the flowers and other insects also most likely use this floral source if present in the habitat. Since there is a reliability of honey bee and lycaenid butterfly pollinatiors in the habitat of the plant species, there is a possibility for the stability of homostylous condition; since this plant is a weed, it is inevitable to have the option of autonomous autogamy which ensures seed set when the pollinators are unreliable or not present either in the same or a new habitat. The study also recommends that intensive field studies are essentially required on floral sexual functions of *M. corchorifolia* in different habitats in order to know whether homostyly is stable or changes into distyly depending on the habitat conditions.

Machado and Sazima (2008) reported that *M. tomentosa* is pollinated by *A. mellifera, Centris* and *Xylocopa*. Ramirez and Navarro (2010) reported that *M. carcasana* is pollinated by flies, bees, wasps and butterflies; *M. parviflora* by bees, wasps and sphingids; and *M. tomentosa* by flies and bees. In this study, *M. corchorifolia* is pollinated by honey bees and lycaenid butterflies. In this species, autonomous autogamy ensures pollination to set certain percentage of seed set and this pollination mode is important enables the plant to build up populations in new situations where pollinator insects are not available or reliable. Insect-mediated pollination increases pollination rate and seed set rate through both self- and cross-pollination. Threfore, *M. corchorifolia* with self-mediated and pollinator-mediated pollination is able to produce large populations and thrive well in different ecological niches.

4. CONCLUSIONS

Abutilon crispum is a shrub and *M. coromandelianum* and *M. corchorifolia* are herbs. They are either annual or perennial depending on the habitat conditions. They occur throughout the year displaying vegetative growth, flowering and fruiting in saturated wet habitats while they are highly seasonal in their growth and reproduction in dry and semi-dry habitats where they appear only during wet season. *G. orbiculata* is a tree species which occurs in dry habitats which are characterized by rocky terrain. It shows leaf shedding, flowering, fruiting and leaf flushing events sequentially. Flowering occurs during dry season and the fruits mature in wet season. All four plant species show anthesis during morning period. They are hermaphroditic, weakly protandrous, self-compatible, monomorphic and homostylous. Autonomous autogamy is functional in *A. crispum, M. coromandelianum* and *M.*

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corchorifolia while it is not functional in *G. orbiculata*. All plant species are facultative autogamous but this mating system is obligately vector-dependent in *G. orbiculata. A. crispum, M. coromandelianum* and *M. corchorifolia* are pollinated by bees and butterflies while *G. orbiculata* is pollinated by thrips and sunbirds. Therefore, facultative autogamy and entomophily ensure these plant species to invade and produce their populations in different ecological niches and flourish as invasive weeds.

Ethical approval

The ethical guidelines for plants & plant materials are followed in the study for sample collection & identification.

Authors contributions:

All authors contributed equally.

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Conflicts of interests

The authors declare that there are no conflicts of interests.

Data and materials availability

All data associated with this study are present in the paper.

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